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RAM B2 FLIGHT TEST OF A METHOD FOR REDUCING RADIO ATTENUATION DURING HYPERSONIC REENTRY

by William F. Cuddihy, Ivan E. Beckwith, and Lyle C. Schroeder

Langley Research Center
Langley Station, Hampton, Va.

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION • WASHINGTON, D.C. • OCTOBER 1963

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RAM B2 FLIGHT TEST OF A METHOD FOR REDUCING RADIO ATTENUATION DURING HYPERSONIC REENTRY*

By William F. Cuddihy, Ivan E. Beckwith,
and Lyle C. Schroeder

SUMMARY

A method of overcoming reentry ionization blackout by injecting water into the flow field was verified by a flight test. Small amounts of water were found to cause radio signal recovery. Maximum vehicle velocity was 17,840 ft/sec at an altitude of 162,200 ft. Frequencies of 30.8 mc, 225.7 mc, 244.3 mc, 5600 mc, and 9210 mc were transmitted from the vehicle. Preliminary information on trajectory parameters, water flow rates, and signal-strength records is presented.

INTRODUCTION

Plasma is formed within the flow field during the flight of a hypersonic vehicle by thermal ionization of the constituents of the air as it is compressed and heated by the strong bow shock or heated within the boundary layer. Free electrons in the plasma interact with electromagnetic radiation to and from the vehicle and cause signal attenuation. The addition of a foreign material may decrease the free-electron concentration and, as a result, the radio attenuation. Possible mechanisms for reducing the local electron concentrations are: (1) increased recombination and attachment as a result of reduced temperatures and increased density; (2) electron attachment by constituents of the additive having an affinity for free electrons (electrophilic action); (3) shock-shape modification by stagnation injection.

There is a large body of literature on reentry communications blackout. References 1 to 6 are representative. Material addition to the flow field may be useful for telemetry, command performance, guidance, tracking, voice communication, and modification of the ionized wake. In practically every survey of possible methods of alleviating blackout, the addition of material to the flow field is included.

The RAM (Radio Attenuation Measurement) research program at Langley Research Center is a comprehensive investigation of reentry communications including theoretical studies, extensive tests in ground facilities, and flight tests designed to provide experimental data on radio attenuation. References 6 to 16 give some results obtained in this program.

*Title, Unclassified.

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On May 28, 1963 a vehicle with a reentry communications experiment (designated RAM B2) was launched from NASA Wallops Station as part of this program. Radio communications which were disrupted by the formation of an ionized layer during hypersonic flight in the earth's atmosphere were readily reestablished by the injection of water into the flow field. This report presents selected data from the RAM B2 material-addition flight and is published without analysis in order to make the information available quickly.

DESCRIPTION OF APPARATUS

Vehicle

The RAM B2 booster vehicle consisted of a Castor motor as the first stage, an Antares motor as the second stage, and an Alcor motor as the third stage. Two spin motors plus canted fins were used to stabilize the vehicle at about 3 rps. Figure 1 is a drawing of the vehicle.

Figure 2 shows the external configuration of the third (payload) stage including the antenna locations and injection sites. The spherical nose was 8 inches in diameter and was followed by a 9° half-angle cone, a 22-inch-diameter cylindrical section, and a flare. A nonablating beryllium heat sink was used on the first 19 inches of the nose cone in order that the effects of material addition on signal loss could be studied with minimum ablation contaminants. Aft sections were covered with a modified epoxy resin or with fiber glass. The most forward antenna was a slot tuned to 244.3 mc. In this same region, four X-band horn antennas were located around the periphery. A 30.8-mc ring antenna was located farther back along the body on the cylindrical section. A 225.7-mc antenna was formed by conical sections which were part of the flare structure. A rearward looking C-band antenna was also located in the flare.

Water-Injection System

The water-injection system is shown schematically in figure 3 and consisted of a pressurized water tank, a squib valve, a distribution valve, and the injection orifices. Since it was considered desirable to keep the injection pressure relatively constant, the water flow rate was varied by changing the number of injection sites. For injection from the stagnation point, up to seven 0.080-inch diameter orifices were used. Side injection sites were located 180° apart and up to ninety-eight 0.015-inch-diameter orifices per side were employed. Figure 4 shows the details and location of the stagnation point and side orifices. The distribution valve was designed to vary the flow rate for stagnation-point injection through seven levels of flow, to provide an off period for attenuation calibration purposes, and to vary the flow injected from side orifices through seven levels.

Range Stations

Receiving stations for the RAM B2 signals with their respective frequency coverage are shown in figure 5. Receiving stations were located at Wallops Station, Va.; Langley Field, Va.; Coquina Beach, N.C.; on a ship in the Atlantic Ocean 315 nautical miles from the launch site on an azimuth of 124.4°; and at Bermuda. Frequency coverage available at each of these stations is also shown in figure 5.

RESULTS AND DISCUSSION

Launch and Trajectory

The RAM B2 vehicle was launched May 28, 1963 at 259:09 edt from the NASA Wallops Station. All systems operated as planned. First-stage burnout occurred 38.4 seconds after launch at an altitude of 33,000 feet; second-stage ignition, at at 50.9 seconds and an altitude of 65,000 feet; second-stage burnout and third-stage ignition at 89.1 seconds and an altitude of 117,000 feet; and third-stage burnout at 118.5 seconds at an altitude of 162,000 feet. The third-stage burnout velocity was 17,840 feet per second. The third stage which included the payload proceeded through the blackout region and reached an apogee of 295,000 feet. Velocity variation with altitude is shown in figure 6. The data were taken during the ascending part of the flight and thereby provided telemetry coverage close to the launch site. Real-time telemetry was transmitted from the 225.7-mc telemetry system and an 80-second delayed playback signal was transmitted from the 244.3-mc telemetry system. Thus, in case of loss of signal due to blackout, the same telemetry information would have been obtained from the playback signal after the third stage had emerged from the blackout region.

Water Flow Rates

Figure 7 shows the variation of water flow rate with time that was obtained during the RAM B2 flight. The water addition was initiated at 110 seconds after launch during third-stage burning. The flow rate was varied for each injection pluse through a range of flows. The maximum flow rate per cycle varied throughout the data period from 1.5 to 0.5 pounds per second and the minimum flow rates varied from 0.3 to 0.06 pound per second. Injection cycles were alternated from stagnation orifices and side orifices. A complete injection sequence lasted approximately 6 seconds and the water-addition period lasted about 70 seconds.

Signal-Strength Measurements

The onset of attenuation occurred at about 100 seconds after lift-off. As the vehicle approached its maximum velocity, the 30.8-mc and 225.7-mc signals were severely attenuated. The 244.3-mc signal which was being transmitted from the forward antenna was blacked out. When water was injected into the flow field, complete recovery was noted for stagnation-point injection and partial recovery for side injection. The C-band signal at 5600 mc and the X-band signal at 9210 m were not noticeably attenuated at any time throughout the flight test.

Some of the signal loss observed during the periods of no water flow can be attributed to antenna detuning which was evident from the voltage standing wave ratio (VSWR) measured for several of the antennas. The VSWR for the 244.3-mc antenna exceeded the meaningful range of the instrument which was about 10. A maximum VSWR value of 7 was recorded for the 30.8-mc antenna. The VSWR values returned to approximately their free-space values during water injection. The VSWR for the 225.7-mc antenna showed only minor variations during the flight.

Figure 8 is a sample of the oscillograph records taken during the data perio and shows several signal strength records for one complete water-injection cycle. The 3-cycle-per-second variation was due to antenna-pattern change with vehicle roll. The cause of the rapid variation of signal strength during stagnation injection is not known but may have been caused by bow-shock oscillations.

Signal-strength measurements for the entire data period (100 to 180 seconds after launch) at frequencies of 244.3 mc, 30.8 mc, and 225.7 mc are given in figure 9. The variations of signal strength due to vehicle roll and the rapid variations during stagnation injection have been removed for clarity by fairing throug the peak values of recorded signals.

244.3-mc signal.- Figure 9(a) shows the signal strength received at the Wallops Station from the 244.3-mc telemetry system. Recovery from blackout was obtained by a flow rate of less than 1/10th of a pound of water per second. For this antenna location substantial recovery was noted for both stagnation and side injection. The upper dashed line indicates the signal level that would have been obtained if there had been no ionization attenuation of the transmitted signal. The lower dashed line indicates the signal level that would have been obtained if there had been no water addition. The solid curve indicates the received signal strength and each recovery pulse coincided with the injection of water.

A narrow band antenna was used here to provide maximum sensitivity to the plasma. Detuning of the antenna occurred because of the presence of the plasma as indicated by a VSWR of greater than 10. Detuning can reduce the efficiency of an antenna and cause an additional signal loss. It is uncertain at this time how much of the measured signal loss should be attributed to detuning effects and how much to plasma attenuation.

30.8-mc signal.- Figure 9(b) shows the signal strength for the 30.8-mc transmitted signal, as received at Coquina Beach, N.C. This is one of the first tests of high-frequency (HF) attenuation measurements under carefully controlled conditions. The signal suffered less attenuation than either of the VHF signals from antennas located fore and aft of this antenna station. However, since the anten designs are different, a direct comparison cannot be made. For this antenna design and location, stagnation-point injection is noted to be more effective th side injection. On several of the recovery pulses for side injection, increased steps in signal strength can be found which correspond to the increasing steps c water flow rate. For example, note the period of 128 to 130 seconds after lift-off in figures 7 and 9(b).

225.7-mc signal.- Figure 9(c) shows the signal strength received at the NASA Wallops Station from the 225.7-mc antenna which was located on the flare of the third stage. This signal as well as the 30.8-mc signal was received throughout the ionization period. Again, during the stagnation-point injection periods, complete recovery of the attenuated signals was noted except prior to third-stage burnout at 118.5 seconds where some effects of rocket-exhaust attenuation could be seen. See reference 17. The effectiveness of the side injection on attenuation was the smallest at this antenna. Since the side-injection system was designed primarily for the forward slot antenna, this reduced effectiveness may have been caused by penetration of water spray well beyond the shock boundary at the 225.7-mc antenna station.

CONCLUDING REMARKS

A flight test has been conducted to determine whether radio communications during reentry can be established by the injection of water into the flow field. Attenuation levels with and without water injection have been measured for frequencies of 30.8 mc, 225.7 mc, 244.3 mc, 5600 mc, and 9210 mc over a range of attitudes at a maximum velocity of 17,840 feet per second. Several antenna locations and designs have been utilized. It has been shown that for the velocities and altitudes of this test, the C-band and higher frequencies were not noticeably attenuated, but the 30.8-mc, 225.7-mc, and 244.3-mc frequencies were attenuated. Relatively small amounts of water have been found to alleviate the attenuation. For this particular system, injection from the stagnation point has been shown to be more effective than injection from a side location.

Although the water-addition concept has been proven to be effective, further work is required to determine the effect of other additives, to achieve the maximum utilization of a given additive, and to extend the results to other shapes and to higher velocities. Tests of material addition combined with various heat-shield ablation products should also be considered.

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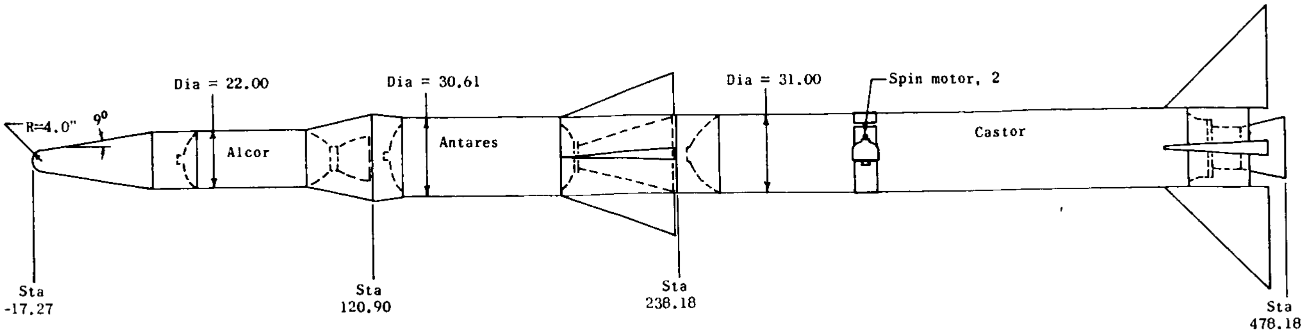
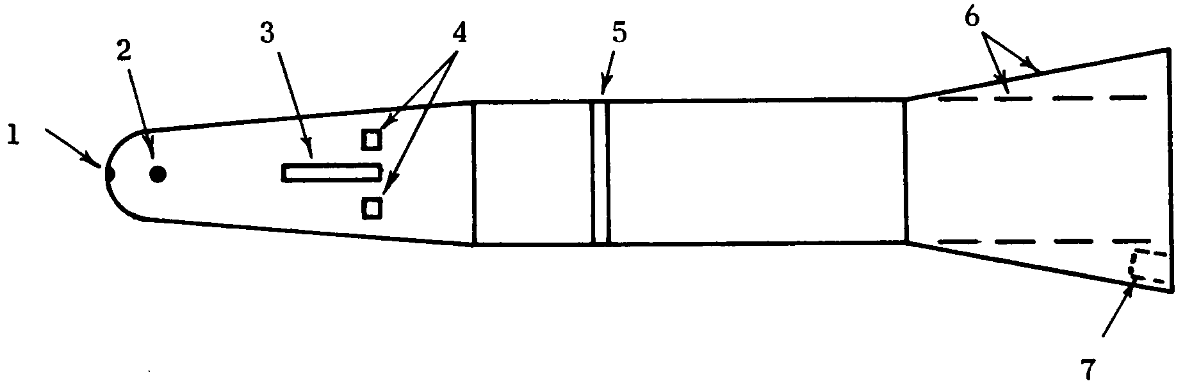


Figure 1.- RAM B2 launch vehicle. All dimensions are in inches.



1. Stagnation injection location
2. Side injection location
3. 244.3 mc VHF antenna
4. 9210 mc X-band antenna
5. 30.8 mc HF antenna
6. 225.7 mc VHF antenna
7. 5600 mc C-band antenna

Figure 2.- External view of RAM B2 third stage showing antenna and injection orifice locations.

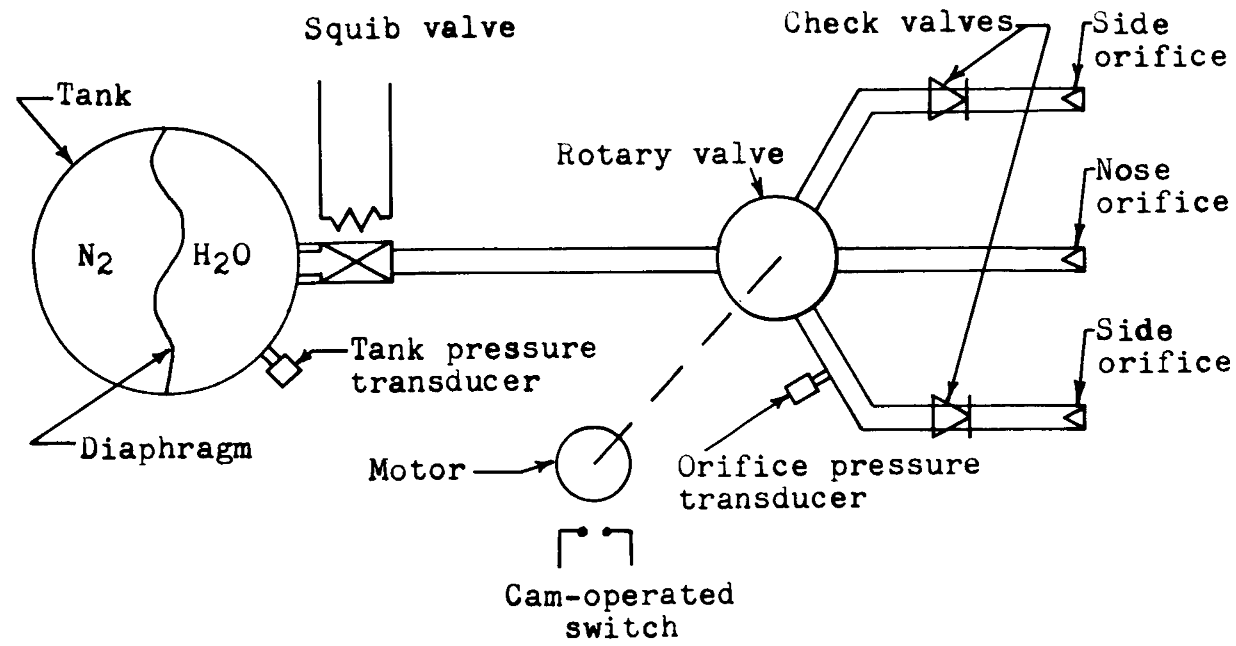


Figure 3.- Schematic diagram of the water-injection system.

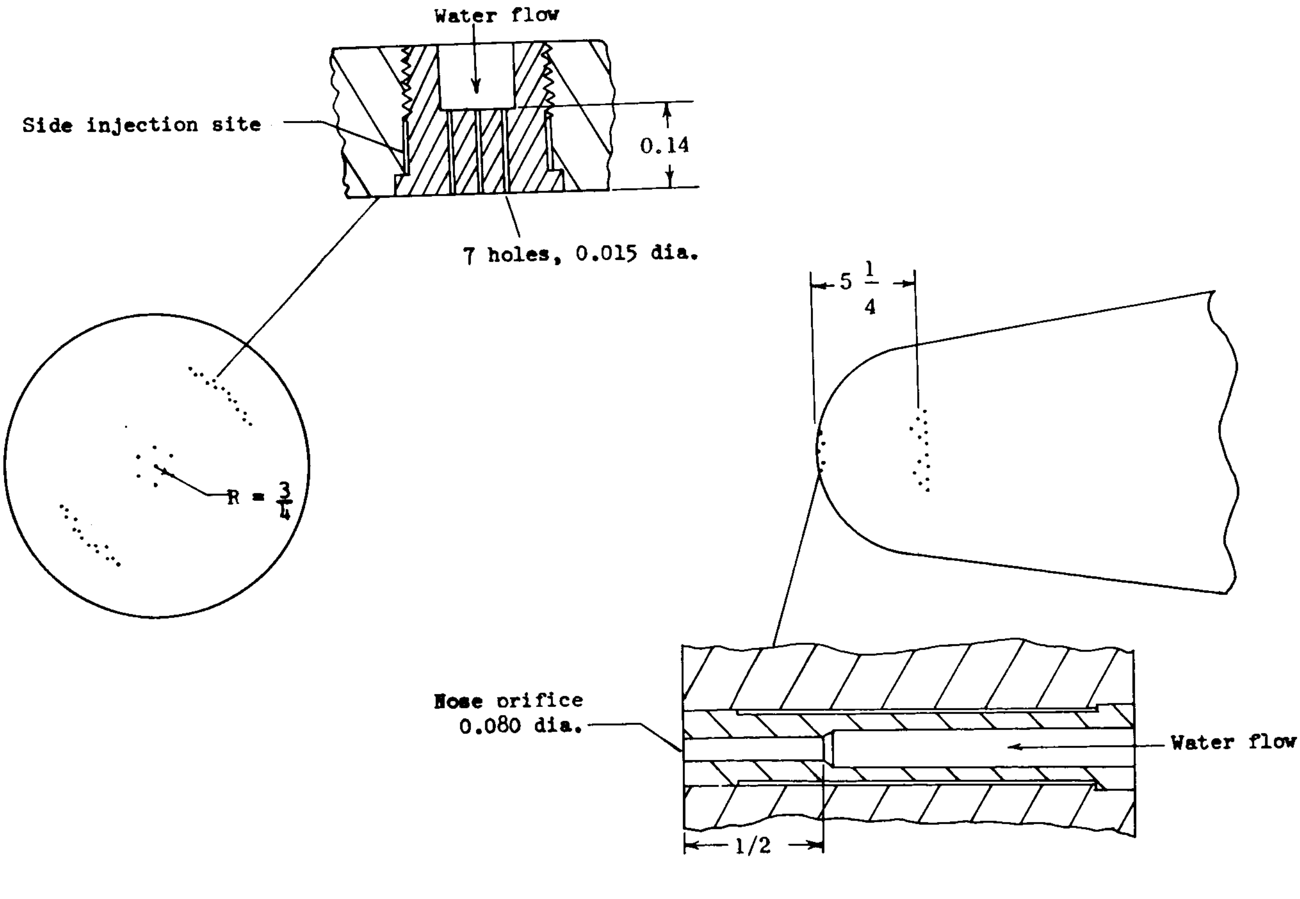


Figure 4.- Details of stagnation-point and side injection orifices. All dimensions are in inches.

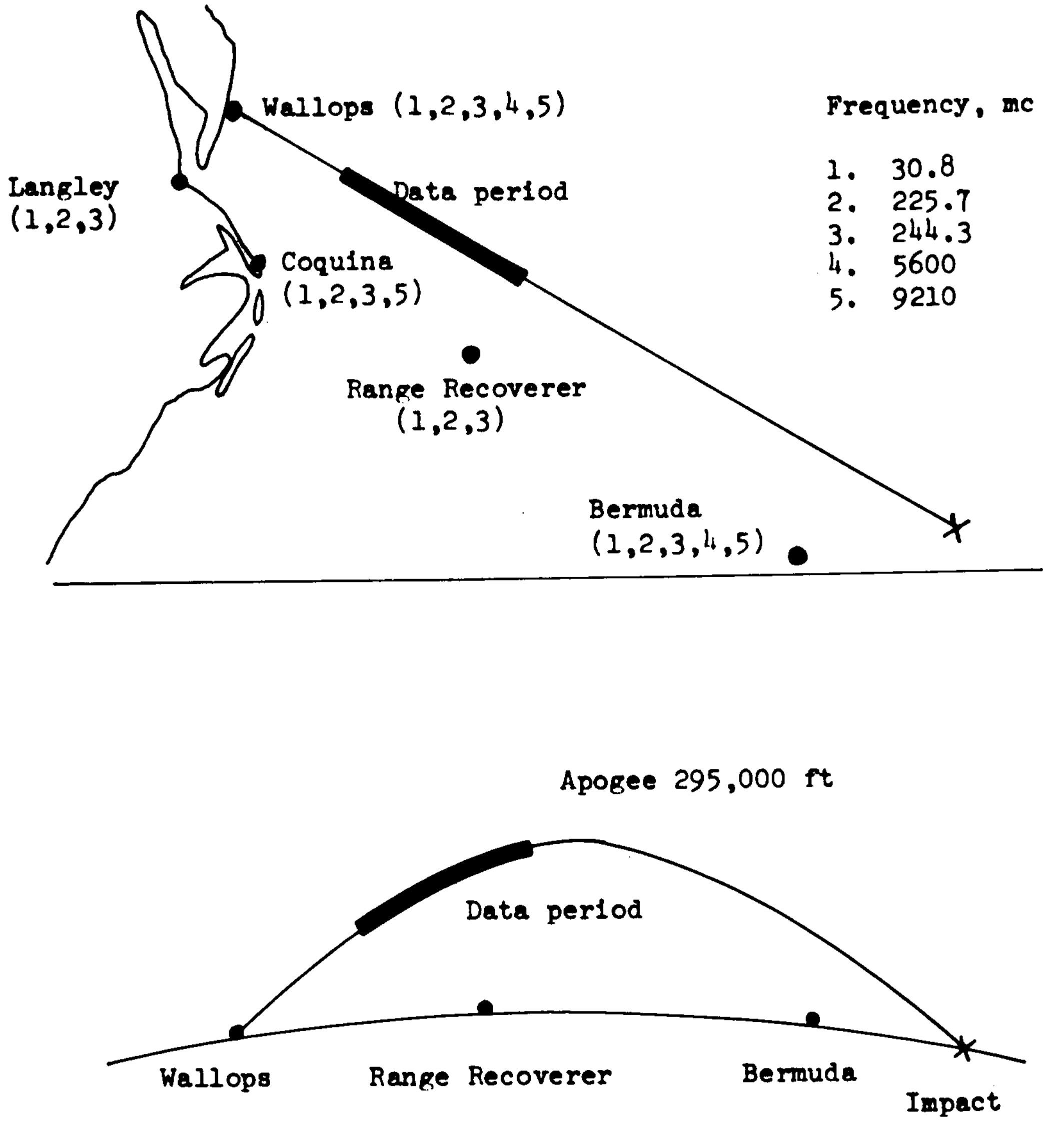


Figure 5.- Receiving stations for the RAM B2 signals with their respective frequency coverage. Frequencies of stations are denoted by numbers in parentheses.

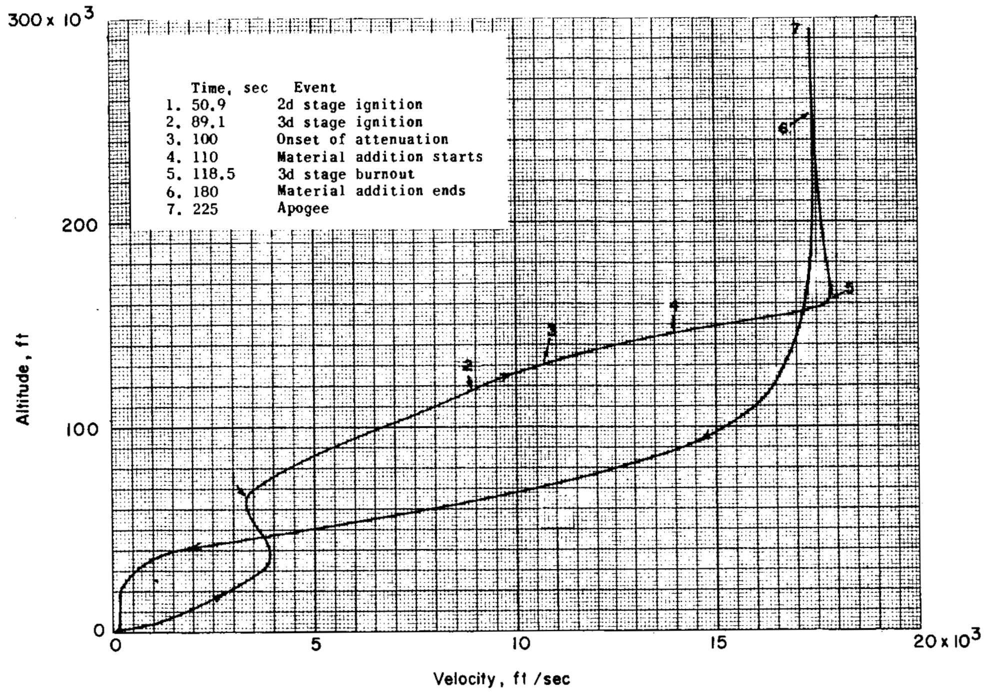


Figure 6.- Variation of altitude with velocity for the RAM B2 flight.

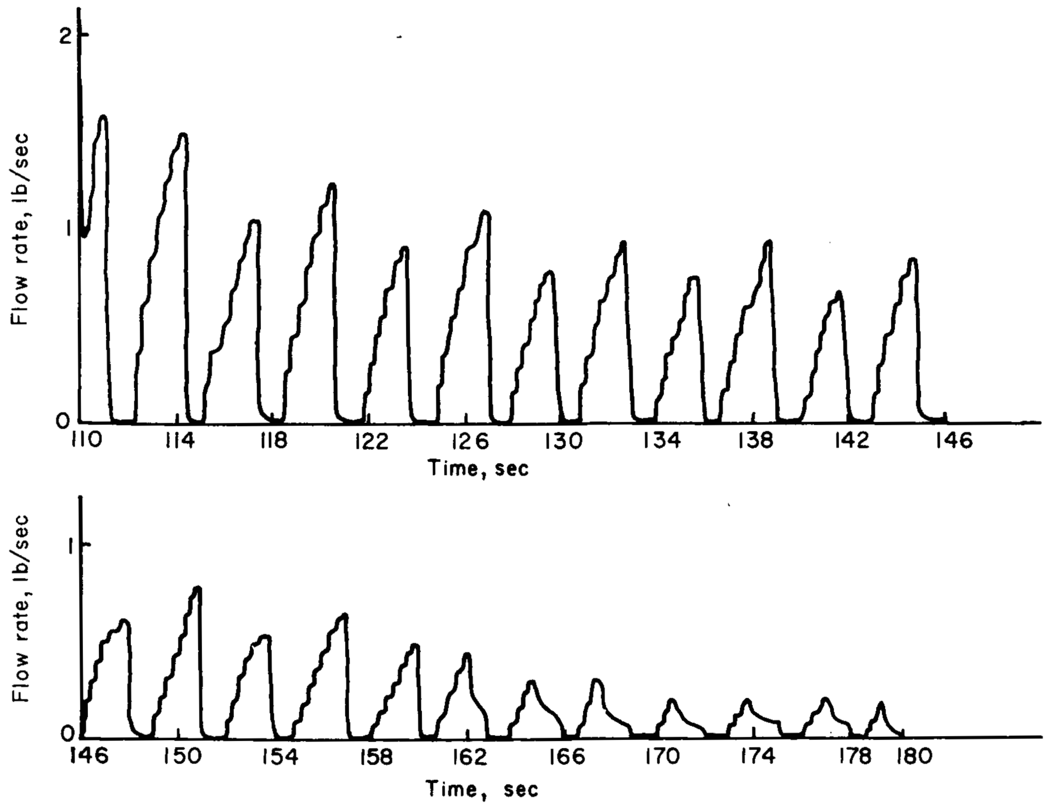


Figure 7.- Variation of water flow rate with time.

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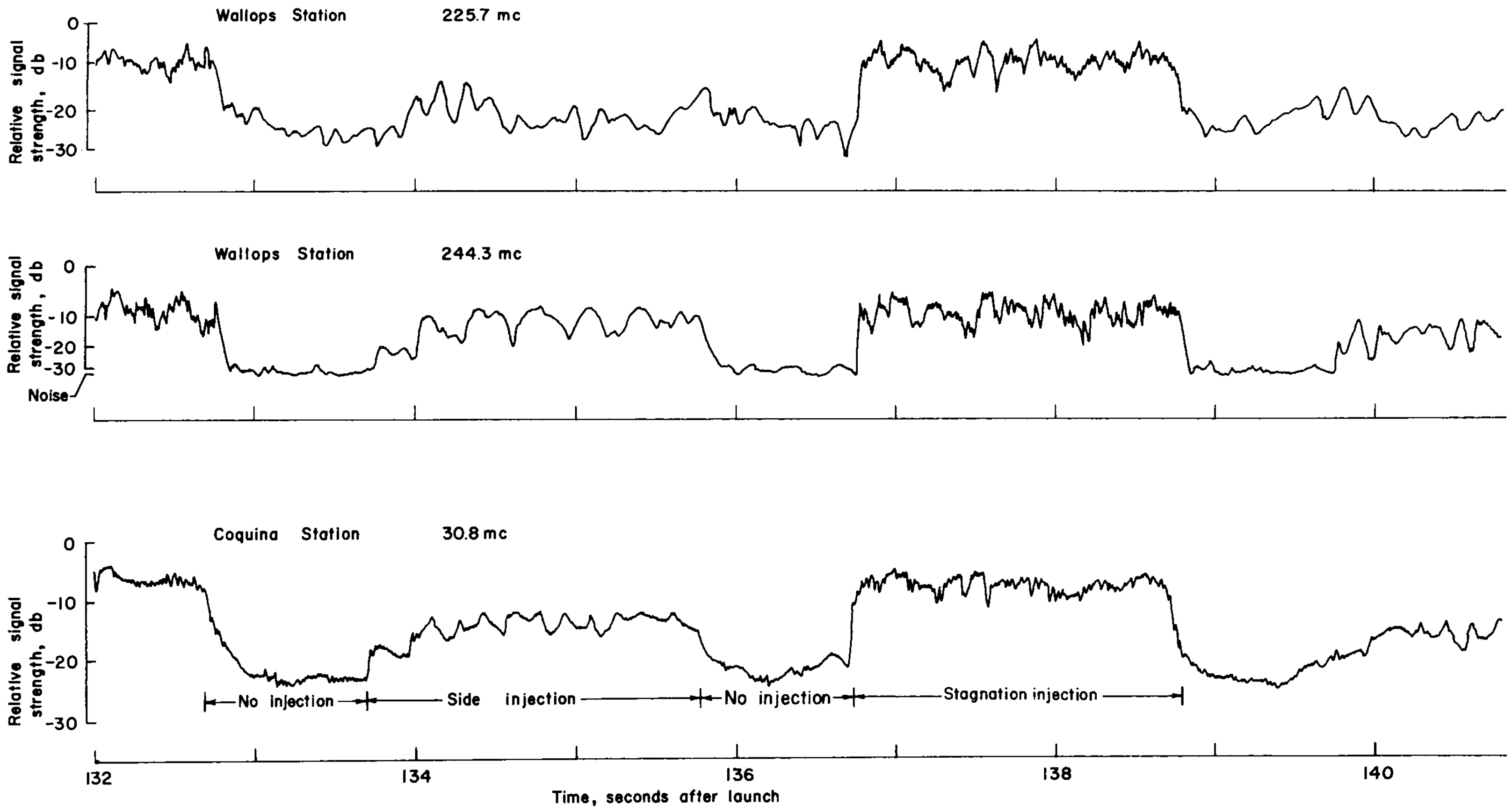

Figure 8.- Typical oscillograph records from selected stations showing the effect of water addition on signal strength.

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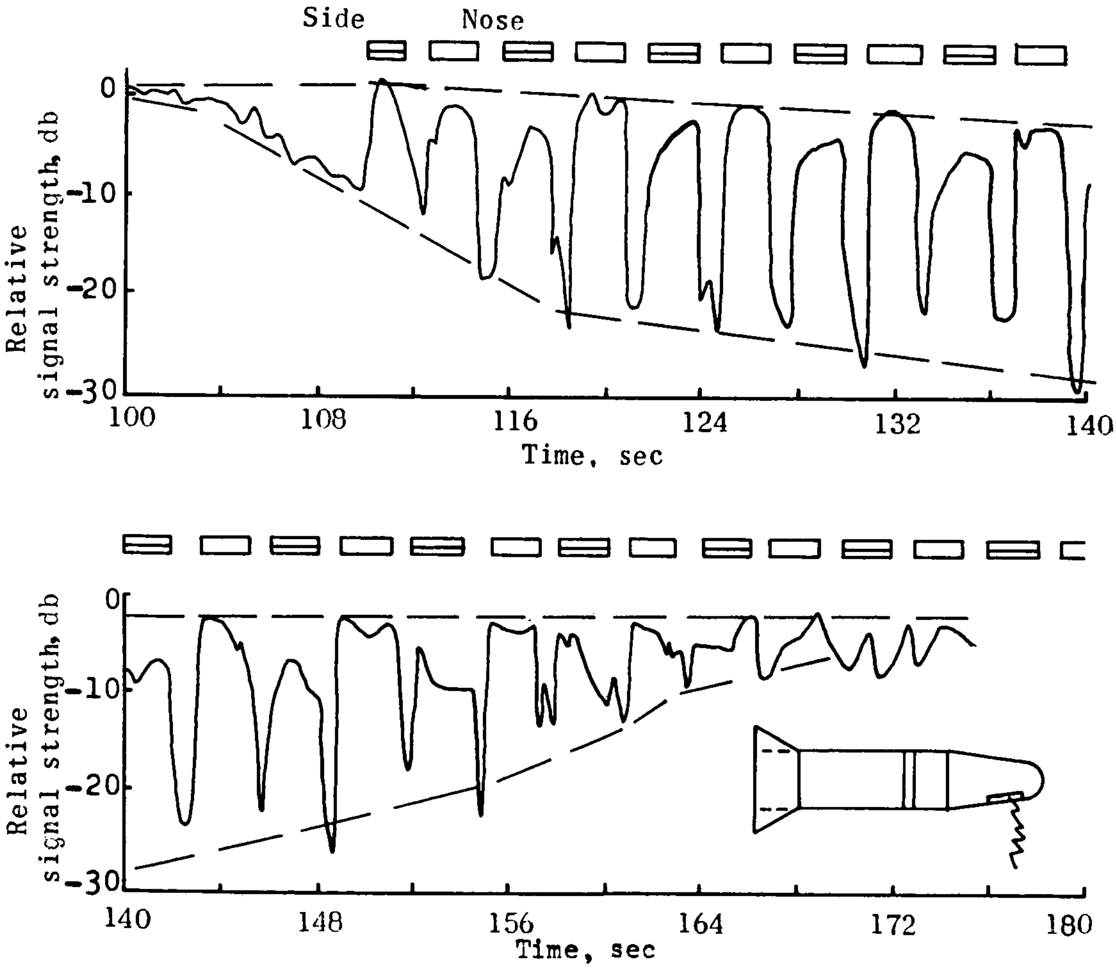
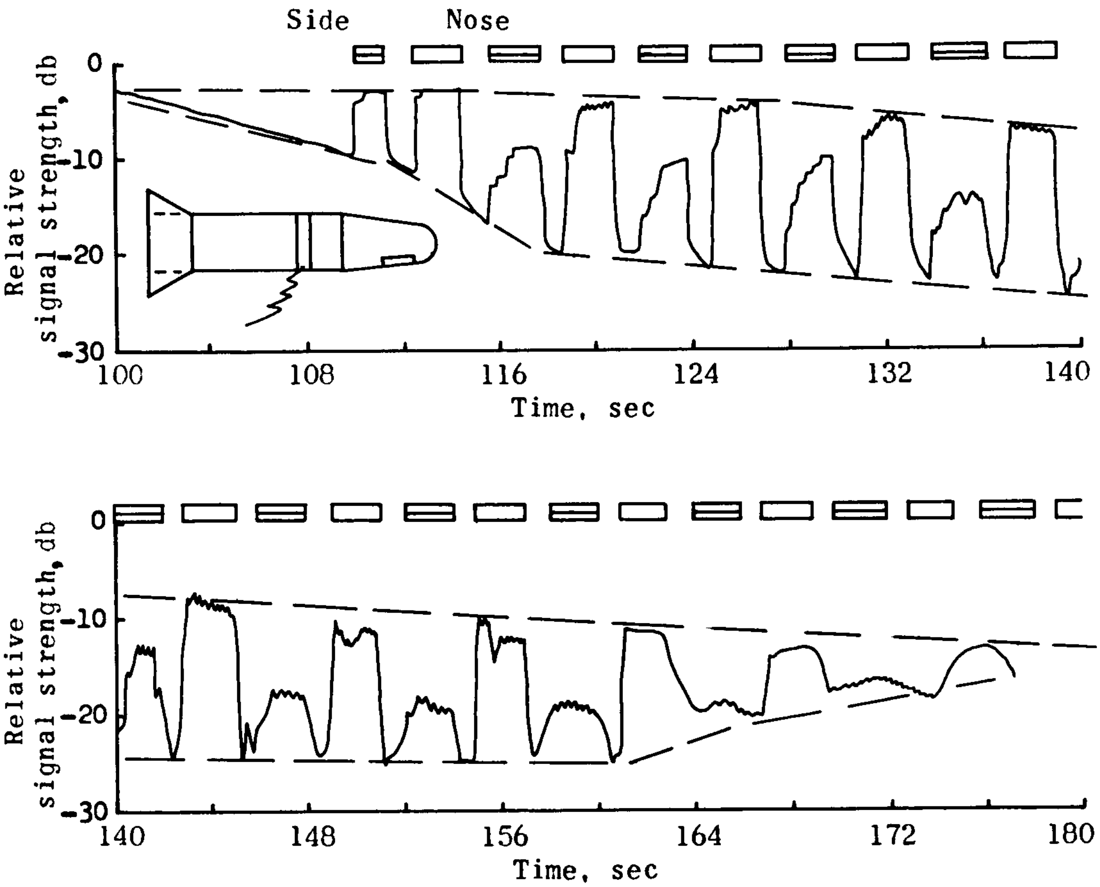


(a) 244.3 mc; NASA Wallops Station.

Figure 9.- Signal strength during data period. Dashed lines indicate signal-level boundaries with and without water injection.



(b) 30.8 mc; Coquina Beach, North Carolina.

Figure 9.- Continued.

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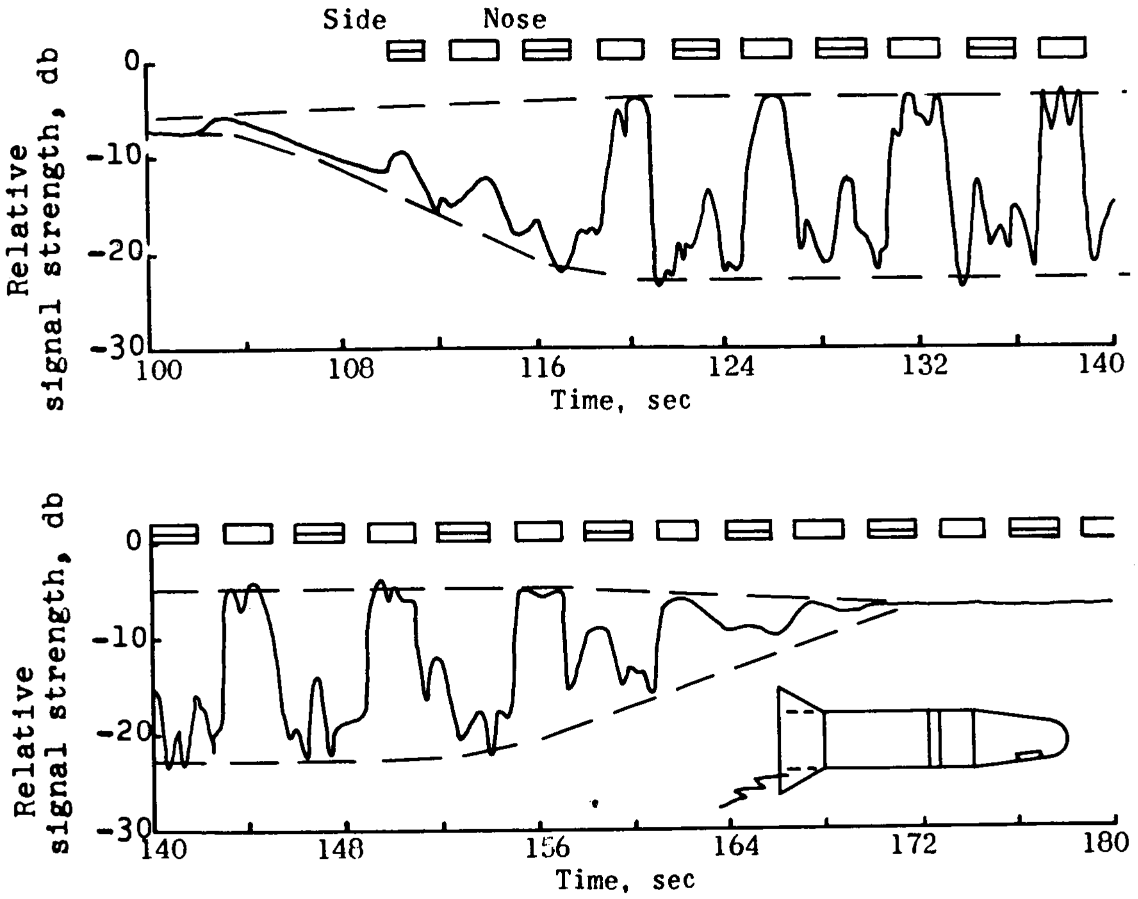

(c) 225.7 mc; NASA Wallops Station.

Figure 9.- Concluded.

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